Results in Physics 5 (2015) 76–77

Contents lists available at ScienceDirect

Results in Physics

journal homepage: www.journals.elsevier.com/results-in-physics

Microarticle

Numerical calculation of relative dose rates from spherical ^{106}Ru beta sources used in ophthalmic brachytherapy

Eduardo de Paiva

Divisão de Física Médica, Instituto de Radioproteção e Dosimetria – IRD/CNEN/MCTI, Av. Salvador Allende s/n, 22783-127 Rio de Janeiro – RJ, Brazil

ARTICLE INFO

Article history:
Received 27 January 2015
Accepted 26 February 2015
Available online 14 March 2015

Keywords:
Brachytherapy
Ophthalmic applicator
^{106}Ru/^{106}Rh

ABSTRACT

Concave beta sources of ^{106}Ru/^{106}Rh are used in radiotherapy to treat ophthalmic tumors. However, a problem that arises is the difficult determination of absorbed dose distributions around such sources mainly because of the small range of the electrons and the steep dose gradients. In this sense, numerical methods have been developed to calculate the dose distributions around the beta applicators. In this work a simple code in Fortran language is developed to estimate the dose rates along the central axis of ^{106}Ru/^{106}Rh curved plaques by numerical integration of the beta point source function and results are compared with other calculated data.

Applicators containing the pure beta emitter ^{106}Ru (main component ^{106}Rh) can be used in ophthalmic brachytherapy for the treatment of various diseases, such as the retinoblastoma and the melanomas of the choroid. A serious drawback of the use of these sources to treat ocular malignancies is the difficulty to perform an accurate dosimetry, mainly because of the high-dose gradient and the short range of the beta-particles as compared with the size of detectors, and in some cases the non-uniform distribution of radioactive material over the plaque surface can bring additional problems on the measurements. Thus, the calculation methods increase in importance and there are two general methods of calculation of dose distribution around beta applicators: Monte Carlo (MC) simulations and analytical and numerical methods. Using MC methods is possible to deal with more complex geometries and different media, and obtain results with great accuracy, but may require a large time of computation; the analytical and numerical methods are based on the beta point-source dose integration, and may give results of dose distributions more rapidly, but apply only for a homogeneous medium.

In this work a Fortran code (which compiler was freely downloaded from the web) was developed to estimate the dose rates along the central axis of CCA and CCB ^{106}Ru applicators by numerical integration of the beta point-source dose function and the results are compared with other semi-empirical analytical [1] and MC calculations [2–5].

The function that describes the absorbed dose rate $J(\xi)$ around a point beta source as a function of the distance ξ can be expressed by [6]

$$J(\xi)=\frac{B}{(\rho v\xi)^2}\left\{c\left[1-\frac{\rho v\xi}{c}\exp\left(1-\frac{\rho v\xi}{c}\right)\right]+\rho v\xi\exp(1-\rho v\xi)-\rho v\xi\exp\left(1-\frac{\rho v\xi}{2}-\frac{f}{2}\right)\right\},\quad(1)$$

where ρ is the medium density and v is the absorption coefficient, with

$$\left[1-\frac{\rho v\xi}{c}\exp\left(1-\frac{\rho v\xi}{c}\right)\right]\equiv 0 \text{ for } \rho v\xi\geqslant c, \text{ and } J(\xi)\equiv 0 \text{ for } \rho v\xi\geqslant f.$$

The parameter B is a normalization constant given by $B=0.046\rho^2v^3\overline{E_\beta}\alpha$, where $\overline{E_\beta}$ is the mean kinetic energy of the beta particles, and the constant α depends on the dimensionless parameters c and f. Eq. (1) is a refinement obtained by Vynckier and Wambersie [6] of the expression firstly proposed by Loevinger [7] in order to obtain a better fit of the beta function to experimental and theoretical data and it is based on the assumption that the strength of the point source follows an inverse-square law, and the radiation is attenuated exponentially when it traverses the medium.

In integration of Eq. (1) the following assumptions were adopted. The eye is formed by a homogeneous medium of density ρ; the radioactive material is uniformly distributed on the concave surface of each plaque; the encapsulation of radioactive material is not considered, and the plaque has spherical symmetry. In Fig. 1 is shown the geometry used in calculation of the dose rate $\dot{D}$ inside the eye by integration of Eq. (1). The source has a constant radius R and an active diameter d; the angle θ is the azimuthal angle in the xy-plane from the x-axis with $0\leqslant\theta\leqslant 2\pi$, and ϕ is the polar angle from the positive z-axis with $0\leqslant\phi\leqslant\phi_{max}$ (ϕ_{max} is defined

E-mail address: epaiva@ird.gov.br

http://dx.doi.org/10.1016/j.rinp.2015.02.006
2211-3797/

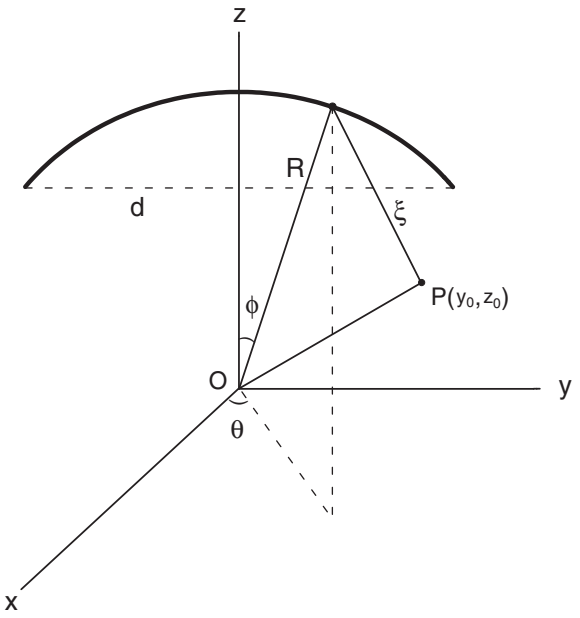

Fig. 1. The geometry of a spherical beta-ray source of radius R and diameter d used for integration of the beta point dose function. Depth increases from the plaque center to the origin O.

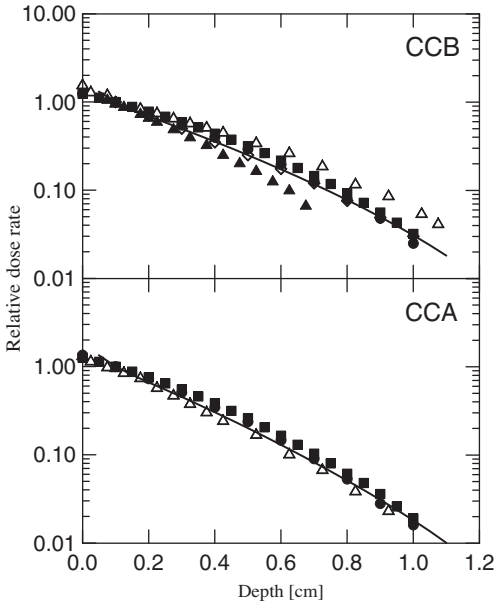

Fig. 2. Relative dose rates along the central axis as a function of the depth for the CCA and CCB ^{106}Ru applicators. Solid lines, this work; •, [5]; ■, [4]; ▲, [3]; △, [2]; ◇, [1].

by the size of the plaque). The distance from the point source to a generic point P(y_0, z_0) is

$$\xi = \left(R^2 + y_0^2 + z_0^2 - 2Rz_0\cos\phi - 2Ry_0\sin\phi\sin\theta\right)^{1/2}. \quad (2)$$

Thus, the absorbed dose rate $\dot{D}$ at P (in plane yz) can be written as

$$\dot{D} = a_S \int_S J(\xi)\cdot dS = a_S R^2 \iint J(\xi)\,\sin\phi\, d\phi\, d\theta, \quad (3)$$

where a_S is the surface activity. This double integration has been performed by means of a Fortran code based on the trapezoidal rule and results are compared with analytical and simulation data.

The Fortran code was used to the numerical integration of the beta point source function (1) to obtain the absorbed dose rates in the region of interest of the CCA ($R = 1.2$ cm , $d = 1.3$ cm) and CCB ($R = 1.2$ cm, $d = 1.78$ cm) curved ophthalmic plaques of ^{106}Ru. In Eqs. (1) through (3) the medium is water; the absorption coefficient v is 3.57 cm^2/g; the mean beta energy per disintegration $\overline{E_\beta}$ is 1.42 MeV; the parameters c, f and α are respectively 0.88, 5.07 and 0.452, and the surface activity a_S is 6.5 MBq/cm^2 for both applicators. In Fig. 2 the absorbed dose rates in water are shown to ^{106}Ru spherical sources. They are plotted against the depth along the z-axis and are relative to the dose at $z = 0.1$ cm. For comparison, published relative dose rates obtained by MC simulations [2–5] and analytical calculation [1] are also shown. For the CCB plaque a good agreement (differences <3%) was found with the analytical results of Ref. [1]. However, a poorer agreement with the MC simulations were found for both plaques mainly at farther distances from the plaque center, and this disagreement may be ascribed to the simplified assumptions adopted.

Despite the simplified assumptions adopted, the method was able to reproduce the general trend of dose values on the central axis of the ophthalmic applicators of ^{106}Ru and can be an auxiliary tool in dose planning.

References

[1] Hokkanen J, Heikkonen J, Holmberg P. Theoretical calculations of dose distributions for beta-ray eye applicators. Med Phys 1997;24:211–3.
[2] Sánchez-Reyes A, Tello JJ, Benjamín G, Salvat F. Monte Carlo calculation of the dose distributions of two ^{106}Ru eye applicators. Radiother Oncol 1998;49:191–6.
[3] Mourtada F, Koch N, Newhauser W. ^{106}Ru/^{106}Rh plaque and proton radiotherapy for ocular melanoma: a comparative dosimetric study. Radiat Prot Dosim 2005;116:454–60.
[4] Hermida-López M. Calculation of dose distributions for 12 ^{106}Ru/^{106}Rh ophthalmic applicator models with the PENELOPE Monte Carlo code. Med Phys 2013;40:101705.
[5] Barbosa NA, da Rosa LAR, de Menezes AF, Reis JP, Facure A, Braz D. Assessment of ocular beta radiation dose distribution due to ^{106}Ru/^{106}Rh brachytherapy applicators using MCNPX Monte Carlo code. Int J Cancer Ther Oncol 2014;2:02038.
[6] Vynckier S, Wambersie A. Dosimetry of beta sources in radiotherapy I. The beta point source dose function. Phys Med Biol 1982;27:1339–47.
[7] Loevinger R, Japha EM, Brownell GL. Discrete radioisotope sources. In: Hine GL, Brownell GL, editors. Radiation dosimetry. New York: Academic; 1956. p. 693–754.